Energy Cost and IAQ Performance of Ventilation Systems and Controls

Project Report # 6 **Meeting Outdoor Air Requirements in Very High Occupant Density Buildings**

A Study of Auditoriums and Schools

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INTRODUCTION

Purpose and Scope of this Report

ASHRAE Standard 62-1989 (and the subsequent Standard 62-1999[1]) raised the outdoor air requirements for acceptable indoor air quality for very high occupant density buildings such as schools and auditoriums from its previous level of 5 cfm per occupant to 15 cfm per occupant. Since occupant densities in these buildings can be very high (e.g. 30-150 occupants per 1000 square feet), the absolute increase in outdoor air volumes in these buildings due to ASHRAE Standard 62 is exceptionally large, and outdoor air fractions (proportion of supply air which is outdoor air) rise significantly. Therefore, air flows in these buildings become heavily dominated by indoor air quality requirements rather than by thermal load requirements. This raises questions as to whether VAV systems can effectively meet the ASHRAE requirements under part load conditions. At part load conditions, supply air flows may be less than the required outdoor air flows unless VAV box minimum flow settings are sufficiently high. However, as VAV box minimum flow settings are raised in VAV systems, the operational characteristics of the VAV system approach that of a CV system (see Project Report #3), so that the energy savings of VAV systems over CV systems may be diminished or lost in these buildings. This further suggests that VAV systems in very high occupant density buildings whose design settings are meant to achieve the ASHRAE requirement of 15 cfm per occupant, may not in actuality be meeting that requirement unless their VAV box minimum flow settings are higher than normal practice would provide.

In addition, other reports in this project document that the impact on annual energy cost and peak energy load which results from raising outdoor air flow rates from 5 cfm to 20 cfm per occupant tends to be larger for high occupant density office buildings than for average occupant density office buildings (see Project Reports # 4 and #5). In these reports, a high occupant density office building was defined as having only 15 occupants per 1000 square feet. This raises the possibility

[1] This project was initiated while ASHRAE Standard 1989 was in effect. However, since the outdoor air flow rates for both the 1989 and 1999 versions are the same, all references to ASHRAE Standard 62 in this report are stated as ASHRAE Standard 62-1999.

that the energy impact of raising outdoor air flow rates to 15 cfm per occupant in education buildings, auditoriums, or other very high occupant density structures could be exceptionally high. On the other hand, very high occupant density buildings also have large internal latent loads. Provided that the outdoor air is dry relative to the return air, raising the outdoor air flow rate should reduce latent loads in these buildings and may tend to reduce, rather than increase, cooling energy use.

The purpose of this report is to examine these issues in detail. This report quantifies the supply and outdoor air flow requirements, assesses outdoor air fractions required, and establishes appropriate VAV box minimum flow settings for a prototype school and a prototype auditorium in three climates. The report also quantifies the energy cost and peak load impacts of raising outdoor air flow rates from 5 to 15 cfm per occupant in these buildings, and examines the potential of energy recovery for reducing annual energy costs and peak loads.

Background

This report is part of a larger modeling project that assesses the compatibilities and trade-offs between energy, indoor air, and thermal comfort objectives in the design and operation of HVAC systems for commercial buildings. The report also attempts to shed light on potential strategies for simultaneously achieving superior performance on each objective. It is hoped that this project will contribute to the body of new data needed by professionals and practitioners who design and operate ventilation systems as they attempt to reduce costs and save energy without sacrificing thermal comfort or outdoor air flow performance.

The methodology used in this project has been to refine and adapt the DOE-2.1E building energy analysis computer program for the specific needs of this study, and to generate a detailed database of the energy use, indoor climate, and outdoor air flow rates of various ventilation systems and control strategies. Constant volume (CV) and variable air volume (VAV) systems in different buildings, with different outdoor air control strategies, in alternative climates provide the basis for parametric variations in the database.

Seven reports, covering the following topics, describe the findings of this project:

- Project Report #1: Project objective and detailed description of the modeling methodology and database development
- Project Report #2: Assessment of energy and outdoor air flow rates in CV and VAV ventilation systems for large office buildings:
- Project Report #3: Assessment of the distribution of outdoor air and the control of thermal comfort in CV and VAV systems for large office buildings
- Project Report #4: Energy impacts of increasing outdoor air flow rates from 5 to 20 cfm per occupant in large office buildings

- ! Project Report #5: Peak load impacts of increasing outdoor air flow rates from 5 to 20 cfm per occupant in large office buildings
- ! Project Report #6: Potential problems in IAQ and energy performance of HVAC systems when outdoor air flow rates are increased from 5 to 15 cfm per occupant in auditoriums, education, and other buildings with very high occupant density
- ! Project Report #7: The energy cost of protecting indoor environmental quality during energy efficiency projects for office and education buildings

DESCRIPTION OF THE BUILDING AND VENTILATION SYSTEMS MODELED

A 2 story L shaped education building, and a single story auditorium were modeled in three different climates representing cold (Minneapolis), temperate (Washington, D.C.), and hot/humid (Miami) climate zones. The education building has 6 perimeter zones representing the four compass directions, and two core zones. The auditorium building includes a core zone auditorium and four perimeter zones representing lobby and office spaces. Exhibit 1 shows key building and HVAC system parameters. Exhibit 2 details the occupancy and HVAC equipment operating schedules modeled. A more complete description of the buildings is contained in Project Report #1.

A dual duct constant volume (CV) system with temperature reset, and a single duct variable volume (VAV) system with reheat were modeled. Constant volume systems control the thermal conditions in the space by altering the temperature of a constant volume of supply air. VAV systems provide control by altering the supply air volume, while maintaining a constant supply air temperature.

For this report, only two basic outdoor air control strategies were employed: constant outdoor air (COA), and temperature-controlled air-side economizer (ECONt). The COA strategy maintains a constant volume of outdoor air irrespective of the supply air volume. The economizer uses additional quantities of outdoor air to provide “free cooling” when the outdoor air temperature is lower than the return air temperature, but is automatically shut off when the outdoor temperature exceeds 65^{o}F to reduce the risk of excess humidity indoors. Below 65^{o}F, the quantity of outdoor air is adjusted so that the desired supply air discharge temperature can be achieved with minimum mechanical cooling. An enthalpy-based economizer is not included for these buildings.

A third basic outdoor air control strategy for VAV systems which was assessed in other reports is a fixed outdoor air fraction (FOAF). The FOAF strategy maintains a constant outdoor air fraction (percent outdoor air) irrespective of the supply air volume. The FOAF strategy does not supply the design outdoor air volumes at part load conditions and is therefore not considered a viable strategy (see Project Reports #2 and #3). The VAV (FOAF) system is therefore not modeled for these buildings. For the CV system, the FOAF strategy is equivalent to the COA strategy since the supply air volume does not change[2].

A more detailed description of these HVAC systems and outdoor air control strategies is provided in Project Report #1.

APPROACH

In this report, the outdoor air quantities for each HVAC system and OA control strategy are determined over the full range of thermal loads. The systems design settings are 5 and 15 cfm of outdoor air per occupant.

Annual energy use (KBtu/ft^2) is converted to energy cost assuming several different energy price structures for all climates. In the base price structure, the price of electricity were assumed to be $.044 per kilowatt-hour, and $7.89 per kilowatt. Gas, which was used in the space and water heating equipment, was modeled at $0.49 per therm. For comparison purposes, energy costs were also computed for four additional price structures that alter the relative price of gas and electricity, and the electricity demand charge. A detailed description of the derivation of these price structures is shown in Project Report #1. Exhibit 3 presents the utility prices under each price structure. Unless otherwise noted, energy costs refer to costs under the base price structure.

The purpose of these pricing variations is to determine how sensitive the conclusions on energy costs are to relative energy prices. Since Minneapolis, Washington, D.C. and Miami are used only to represent different climate conditions, no attempt was made to use the actual energy prices in these individual cities.

RESULTS

The presentation of results is organized to shed light on the following questions:

a. How high must minimum VAV box settings be to accommodate both the ASHRAE Standard 62-1999 outdoor air requirements, and the thermal load requirements of very high occupant density buildings? How do these settings affect the viability and operational integrity of HVAC system controls in these buildings?

b. What are the energy cost and peak load impacts of raising the outdoor air requirements from 5 cfm per occupant to 15 cfm per occupant in very high occupant density buildings?

c. Given the large outdoor air volumes required in these buildings, what gains may be derived from energy recovery technologies in these buildings?

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[2] For consistency with other project reports, the CV(FOAF) rather than the CV(COA) designation is used in this report.

Design Versus Actual Outdoor Air Flows

Exhibit 4 presents the percent of occupied hours that specified outdoor air volumes were achieved in the simulations for design outdoor air volumes of 5 and 15 cfm per occupant. For the VAV systems in these runs, the VAV box minimums are set at 30% of peak flow.

As expected, CV systems for both the education and assembly building brought in the requisite quantities of outdoor air 100% of the time in all climates at both outdoor air settings of 5 and 15 cfm per occupant. The VAV(COA) system also delivered requisite quantities of outdoor air 100% of the time at a design setting of 5 cfm per occupant, with a VAV box setting of 30%. However, when the outdoor air setting was changed to 15 cfm per occupant, the VAV box minimum setting of 30% was inadequate, and less than 15 cfm per occupant entered the building at part load conditions. This is most notable for the assembly building which has a higher occupant density. For example, for the assembly building in Washington, D.C. and in Minneapolis, the VAV(COA) system delivered less than 10 cfm of outdoor air per occupant 70% and 79% of the time respectively. The problem is less dramatic for Miami because there is a smaller proportion of time spent in part load conditions in the Miami climate.

VAV Box Minimum Setting

The inadequate outdoor air flow with the VAV(COA) system is not due to the outdoor air flow strategy at the air handler. By definition, the COA strategy insures an adequate supply of outdoor air by increasing the outdoor air fraction at part load conditions. Rather, the problem in this case is with the VAV box minimum settings. Under part load conditions, a VAV box minimum setting of 30% allowed the supply air volume to fall below the outdoor air volume required to meet the 15 cfm per occupant outdoor air requirement. This means that the supply air needed to meet thermal loads at part load is insufficient to meet the outdoor air requirement, even at 100% outdoor air.

To solve this problem, simulations were run allowing DOE-2.1E to automatically establish the VAV box minimum settings necessary to guarantee 15 cfm per occupant of outdoor air under all operating conditions. The minimum settings required are presented in Exhibit 5.

The VAV box minimum settings required are substantially higher than 30%. VAV box minimum settings for perimeter zones ranged from 38% - 56% in the education building, and from 39% - 65% in the assembly building. However, in the core zone, minimums ranged from 54%-71% in the education building, and from 95% - 100% for the assembly building. These settings are much higher than are normally provided.

Exhibit 6 demonstrates that only properly adjusted (higher) VAV box minimum settings insured that the design outdoor air volume of 15 cfm per occupant is actually met at all operating conditions.

Outdoor Air Fraction

The high VAV box settings suggest that the supply air volumes cannot be reduced substantially in these buildings in response to reduced thermal loads. Exhibit 7 presents the supply volumes and outdoor air fractions which result from HVAC systems in which the VAV box minimum settings are properly adjusted. It is clear that these HVAC systems are easily dominated by the outdoor air requirement rather than the thermal requirement. In this case the VAV system operates very similarly to the CV system. Further, the outdoor air fractions under both design and minimum load conditions are considerably higher than the 10% to 30% normally assumed for office buildings. A design outdoor air fraction of 42%-48% is required for the education building, and 65%-75% for the assembly building. The outdoor air fraction at minimum load is 100% for both buildings.

Control of Temperature and Relative Humidity

Exhibit 8 presents data showing the proportion of time the average space air temperature for all zones fell within specified temperature bins. This data suggests that all the HVAC systems kept indoor temperatures between 70^{o}F and 79^{o}F virtually all the time. This is true for both the education and assembly building in all three climates. Examination of zone specific temperatures showed a similar pattern in each zone for all systems. All the HVAC systems appear to adequately control indoor temperature. This indicates the systems were adequately sized to meet sensible loads.

These systems, however, depend on the cooling system to control relative humidity in the occupied spaces. Given the high occupant densities in these buildings, the internal latent loads are high. Since the required outdoor air quantities are also high, the cooling system may not adequately control relative humidity as it controls temperature. Exhibit 9 shows that, without specific humidity controls, the average zone relative humidity often exceeded 60%, and occasionally exceeded 70%. Because of this, the buildings were also modeled to control relative humidity to 60% by lowering the cooling coil temperature when required to meet the latent load.

Annual Energy Cost

Exhibit 10 and Exhibit 11 present the annual energy costs for outdoor air settings of 5 and 15 cfm per occupant for the education and assembly building respectively. Exhibit 12 and Exhibit 13 present the absolute and percentage changes in cost.

Energy Cost Impact of Raising Outdoor Air Flow Rates from 5 to 15 CFM Per Occupant

Project Report # 4 suggests that raising outdoor air flow rates would have only modest impacts on energy use and energy costs for most office buildings, and may, in some buildings, actually reduce rather than raise costs. However, the picture is quite different for very high occupant density buildings such as education and assembly buildings. Raising outdoor air flow rates in these buildings can raise energy costs substantially.

Exhibit 12 and Exhibit 13 demonstrate that only part of the energy cost increase results from raising the outdoor air design setting from 5 cfm to 15 cfm per occupant. For CV systems, a change in design setting alone raised energy costs by 14% to 31% for education buildings and by 19% to 50% in auditoriums. For the VAV system, a change in design setting alone raised energy costs by 14% to 19% for education buildings and by 16% to 23% for assembly buildings. However, as noted above, for VAV systems, changing the outdoor air setting alone, without changing the VAV box setting, did not provide 15 cfm of outdoor air under part load conditions. Therefore, these costs do not reflect the full costs of raising the outdoor air flow rates. When the VAV box minimum flow settings are also adjusted to insure adequate outdoor air flow, the energy costs of raising outdoor air flow rates to15 cfm per occupant for VAV systems were 15%-32% for education buildings, and 25% - 67% for auditoriums.

Finally, because controlling temperature in both the CV and VAV systems did not adequately control the relative humidity in the occupied space when outdoor air flows were 15 cfm per occupant, adding humidity control to 60% relative humidity raised the energy cost impact to between 17% and 39% for CV systems in education buildings, and between 26% and 58% for CV systems in auditoriums. The energy cost impact for VAV systems was 15% to 35% in education buildings, and 35% to 81% in auditoriums. These increases are much larger than is normally assumed.

These increases reflect utility prices under the base price structure used in this study. However, Exhibit 14 and Exhibit 15 demonstrate that the energy cost increase is very large under all the price structures analyzed in this project (Exhibit 3).

Climate Effects

The energy cost impacts of raising outdoor air flow rates from 5 cfm to 15 cfm per occupant were greater in the cold and temperate climates of Minneapolis and Washington, D.C., than in the hot and humid climate of Miami. This conclusion also runs contrary to popular belief. The reason is that while hot humid climates experience the largest absolute increment in cooling costs, heating costs rose dramatically in temperate and cold climates when outdoor air flow rates are raised to 15 cfm per occupant, but rose only slightly in the hot and humid climate. As a result, the annual energy cost increase in both absolute and percentage terms was much greater for the cold and temperate climate than it was in the hot and humid climate. This is true for all five utility price structures.

Heating System Effects of CV and VAV Systems

The CV and VAV systems modeled have significantly different relative heating cost impacts of increased outdoor air. In both systems the OA requirement was the same. In the CV systems, heating costs rose substantially when outdoor air flow rates were increased from 5 to 15 cfm per occupant because of the need to heat cold outside air during cold weather. The effect on heating energy for VAV systems, however, was not the same. Since the VAV system has zone reheat, heating does not occur until after the air passes through the cooling coil. Since the discharge temperature of the supply air from the cooling coil is approximately the same at 5 cfm as it is at 15 cfm per occupant, there would ordinarily be no substantial impact on heating energy.

In office (lower occupant density) buildings, the outdoor air fraction is usually too low to force the mixed air temperature below 45°F so that preheat was not normally necessary. But for the very high occupant density buildings modeled here, the outdoor air fraction is very high. This means that in very cold weather, preheat coils in the VAV system are activated to heat the air <u>before</u> it enters the cooling coil to avoid freezing the coil. The large volumes of outdoor air during cold weather may reduce cooling energy costs in VAV systems, as would an economizer, but at a heating cost penalty, which in this case is a preheat penalty [3].

The large jump in heating costs in the VAV system occured when the VAV box minimum settings are adjusted to raise the outdoor air volumes at part load conditions. This raised the outdoor air fraction and resulted in colder mixed air temperature on cold winter days. This created a larger outdoor air heating burden at the preheat coil.

In very high occupant density buildings with VAV systems, most of the increase in heating was the additional preheat coil load, while heating coil loads were only moderately affected. In contrast, CV systems in the same buildings had much more profound central heating coil loads, and less burden on the preheat coil.

Economizers

At 5 cfm of outdoor air per occupant, the economizer reduced cooling energy costs by approximately $.05 per square foot in the Minneapolis and Washington, D.C. climates, by raising outdoor air volumes when the outdoor air was cooler than the return air. Economizers have little or no advantage in Miami[4]. However, when the outdoor air volume was raised to 15 cfm per occupant in these very high occupant density buildings, much of the economizer advantage was already accounted for by these high outdoor air flow rates. In fact, for VAV systems, the economizers never became operational because additional quantities of outdoor air were not needed to reduce cooling costs. The VAV(COA) and the VAV(COA)(ECON) systems were therefore operationally identical.

Integrity of VAV Systems

At 5 cfm of outdoor air per occupant, the VAV system had a significant energy advantage over the CV systems because of reduced fan energy and cooling energy costs for both the education and assembly building. At 15 cfm per occupant, with appropriate adjustments of the VAV box and control of relative humidity at 60%, the VAV system had similar advantages in the education building. However, when occupant densities rose again, as in the auditorium, the advantages of

[3] See Project Report # 5 for discussion of this effect in office buildings

[4] For a more detailed explanation of economizer advantages, see Project Report # 2.

the VAV system disappeared. In fact, in the auditorium, the VAV system cost more to operate than the CV system. Both the cooling cost and the heating cost were higher for the VAV system than for the CV system in the auditorium. The air flows of the VAV system were operating similar to the air flows of the CV system, but the CV system, with its dual duct and temperature reset capability is more efficient than the single duct VAV system with zone reheat under these conditions. This suggests that VAV systems may not be appropriate in auditoriums, or similar buildings where the occupant densities are extraordinarily high.

Peak Load Impacts of Raising Outdoor Air Flow Rates to 15 CFM Per Occupant

Exhibit 16 - 19 present peak load data for both 5 and 15 cfm of outdoor air per occupant. Changes in peak loads shed light on whether or not existing systems sized to provide 5 cfm of outdoor air per occupant are likely to have sufficient capacity to also provide 15 cfm per occupant without retrofit. In addition, peak loads at 15 cfm per occupant provide some measure of the potential for downsizing equipment in energy conservation retrofits.

Peak Cooling Load

Peak cooling loads for CV systems were increased by 20% - 26% in the education building and by 30% - 32% in the auditorium. For the VAV system, peak cooling loads were increased 20%- 26% in the education building, and by 21%- 28% in the auditorium. These increases are substantial. It suggests that buildings sized for 5 cfm per occupant will probably not be capable of achieving 15 cfm per occupant with the same cooling equipment, and that energy retrofits of existing buildings which are also being redesigned to meet ASHRAE 62-1999 may be severely limited in how much downsizing can actually take place.

Peak Heating Coil Loads

Peak heating loads for CV systems in Minneapolis and Washington, D.C. increased by 12% - 30% in the education building, and by 3% - 22% in the auditorium. For VAV systems in Minneapolis and Washington, D.C., peak heating loads increased less than 10% for the education building, and by 9%-22% for the auditorium. In Miami, the peak heating loads were negligible at 5 cfm of outdoor air per occupant for both the education building and the auditorium. However, at 15 cfm per occupant, peak heating coil loads rose to 480 - 520 k BTU/hr.

These results suggest raising outdoor air flow rates to 15 cfm per occupancy results in only modest increases on the main heating coil, and these increases could probably be accommodated with existing systems designed for 5 cfm per occupant. However, in hot and humid climates such as Miami, the peak heating coil loads at 15 cfm per occupant, while small, may be more than current systems are designed to handle.

Peak Preheat Coil Loads

At 5 cfm of outdoor air per occupant, no preheat coil loads were experienced for any CV system in either the education or assembly building in any climate modeled. When outdoor air volumes were increased to 15 cfm per occupant, preheat coil requirements appeared in Minneapolis and Washington, D.C. They were highest in Minneapolis and were greater in the auditorium than in the education building. In the auditorium in Minneapolis, peak preheat coil loads exceeded 1000 kBTU/hr. No preheat requirements were experienced for CV systems in Miami either at 5 or 15 cfm per occupant.

A similar pattern is presented for VAV systems. In Minneapolis, peak preheat coil loads went from 246 to 1282 kBTU/hr in education buildings, and from 330 to 919 kBTU/hr in auditoriums when outdoor air volumes were increased from 5 to 15 cfm per occupant. Smaller increases were experienced in Washington, D.C. and Miami.

Many systems have little or no preheat coil loads at 5 cfm per occupant. The emergence of a preheat load means that existing systems designed at 5 cfm per occupant may experience significant damage from coil freezing if run to accommodate 15 cfm per occupant without adding preheat coil capacity. It also means that new systems must include preheat coils to accommodate 15 cfm of outdoor air per occupant. The problem is especially prevalent in cold climates (e.g., Minneapolis), but the emergence of even a small preheat coil requirement could portend freezing damage if it is not available.

Potential for Energy Recovery Technology

The substantial increase in energy cost associated with raising outdoor air flow to meet ASHRAE Standard 62-1999 for education and assembly buildings constitutes a significant potential savings for efficient energy recovery technology. The extent to which such a potential could be realized was not modeled because DOE-2.1E is extremely limited in its ability to model energy recovery systems. However, some literature suggests that available energy recovery technology can significantly reduce or eliminate the increased energy cost and further improve the potential to downsize equipment in these buildings (Rengarajan, et al. 1996; Shirey et al. 1996)

SUMMARY & CONCLUSIONS

VAV systems derive much of their attractiveness for energy conservation by their ability to save fan energy during part load conditions. However, in buildings with high occupant densities, such as the schools and auditoriums, the high outdoor air volumes required by ASHRAE Standard 62-1999 places a floor on the extent to which VAV systems can pinch down during part load, so that VAV systems in these buildings operate more like CV systems when meeting the outdoor air requirements of ASHRAE Standard 62-1999. The VAV box minimum settings must necessarily be much higher than are typically used for office environments in order to provide sufficient outdoor air. This, in part, explains the higher energy cost associated with raising the outdoor air setting from 5 cfm to 15 cfm per occupant in these buildings. Economizers may not have much advantage in high occupant density buildings because much of the advantage of economizers is already accounted for by the higher outdoor air flow rates. In fact, the economizer for the VAV system never became operational when 15 cfm of outdoor air was maintained in the school and education building.

In most office buildings, when the cooling plant is sized to meet the sensible load, the latent load is most often also satisfied. However, in schools and auditoriums, when the cooling plan twas sized to meet the sensible load at 15 cfm per occupant, the latent load was most often not accommodated, raising the relative humidity often above 60% and occasionally above 70% in the occupied spaces.

Unlike office buildings, when outdoor air flow rates were raised from 5 to 20 cfm per occupant in the education and assembly buildings, energy costs increased substantially. The HVAC energy cost increase of raising outdoor air flow rates was 17% to 39% for CV systems in education buildings, and 26% to 58% for CV systems in auditoriums. The HVAC energy cost impact for VAV systems was 15% to 35% in education buildings, and 35% to 81% in auditoriums. These increases were partly due to raising the outdoor air flow settings, partly due to changing the VAV box minimum settings to insure adequate outdoor air flow, and partly due to the need to control humidity to below 60%.

Peak cooling loads increased 20%-32% when raising outdoor air flow rates from 5-15 cfm per occupant, while only modest increases in the main heating coil were experienced. However, peak preheat coil loads were also substantially increased. Many systems have little or no preheat coil loads at 5 cfm per occupant. Thus, existing systems designed for 5 cfm of outdoor air per occupant may not be capable of maintaining thermal comfort during heavy loads. In addition, the emergence of a preheat load means that existing systems designed at 5 cfm per occupant may experience significant damage from coil freezing if run at 15 cfm per occupant without adding preheat coil capacity.

The higher peak loads also suggest that meeting ASHRAE 62-1999 during an energy retrofit places severe limitations on the extent to which cooling equipment can be downsized. The increased annual energy cost and the effect on equipment capacity make the use of energy recovery systems potentially very attractive to high occupant density building, and further research into this potential would be useful.

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Exhibit 1: Characteristics of the Base Buildings Modeled in this Study

	Education	Assembly
Building Characteristics		
shape	L-shaped	square
zones/floor	6	5
floor area (ft^2)	50,600	19,600
number of floors	2	1
floor height (ft)	15	30
wall construction	concrete block	concrete block
net window area (%)	34%	7%
window U-value (Btu/hr ft^2 ^0F)	0.59	0.59
window shading coefficient	0.6	0.6
wall R-value (hr ft^2 ^0F/Btu)	R-8	R-8
roof R-value (hr ft^2 ^0F/Btu)	R-12	R-12
perimeter/core ratio*	1.0	0.6
infiltration rate (ach)	0.25	0.25
Occupancy		
number of occupants	1,518	588
occupant density (occup/1000ft^2)	30	60
HVAC		
air distribution system	central (CVor VAV)	central (CVor VAV)
heating and DHW	central gas boiler - 80% efficiency	central gas boiler - 80% efficiency
cooling	chiller - 4 COP w/cooling tower	chiller - 4 COP w/cooling tower

* Ratio of perimeter to core floor area, where perimeter space is up to 15 ft. from the exterior walls

Exhibit 2: Occupant & Operating Schedules for Office, Education, and Assembly Buildings

	Office Building					Education Building						Assembly			
	Occupancy		HVAC			Occupancy			HVAC			Occupancy		HVAC	
Hour	Mon-Fri	WE/ Hol	Mon	Tue-Fri	WE/ Hol	Mon-Fri	Sat.	Sun/ Hol	Mon-Fri	Sat	Sun/ Hol	Mon-Fri	WE/ Hol	Mon-Fri	WE/ Hol
1-5	0%	0%	night	night	night	0%	0%	0%	night	night	night	0%	0%	night	night
6	0%	0%	St Up	night	night	0%	0%	0%	St Up	St Up	night	0%	0%	night	night
7	0%	0%	St Up	St Up	night	0%	0%	0%	St Up	St Up	night	0%	0%	night	night
8	25%	0%	day	day	night	10%	0%	0%	day	day	night	0%	0%	night	night
9	75%	0%	day	day	night	100%	10%	0%	day	day	night	10%	10%	St Up	St Up
10-12	95%	0%	day	day	night	100%	10%	0%	day	day	night	10%	10%	day	day
13	75%	0%	day	day	night	100%	10%	0%	day	day	night	50%	75%	day	day
14-15	95%	0%	day	day	night	100%	0%	0%	day	day	night	50%	75%	day	day
16	95%	0%	day	day	night	50%	0%	0%	day	day	night	50%	75%	day	day
17	75%	0%	day	day	night	50%	0%	0%	day	day	night	50%	75%	day	day
18	50%	0%	day	day	night	50%	0%	0%	day	day	night	50%	75%	day	day
19	25%	0%	night	night	night	15%	0%	0%	day	night	night	100%	100%	day	day
20-21	10%	0%	night	night	night	20%	0%	0%	day	night	night	100%	100%	day	day
22	10%	0%	night	night	night	10%	0%	0%	day	night	night	100%	100%	day	day
23-24	0%	0%	night	night	night	0%	0%	0%	night	night	night	50%	75%	day	day

St Up = startup; day = full operation; night = operating with night temperature set back of 10^{0}F.

Exhibit 3
Utility Rate Structures Modeled

	Rate Class			Rate Structure			
Rate Structures	**Gas Rate**	**Electric Rate**	**Electric Demand**	**Gas Rate**	**Electric Rate**	**Electric Demand**	**Ratchet Clause**
Base	Average	Average	Average	$0.490	$0.044	$7.890	No
Option 1	Low	High	Average	$0.330	$0.063	$7.890	No
Option 2	High	Low	Average	$0.650	$0.025	$7.890	No
Option 3	Average	Average	High	$0.490	$0.044	$11.710	No
Option 4	Average	Average	Low	$0.490	$0.044	$4.070	No

Exhibit 4
Percent of Occupied Hours Air Flows are Achieved for Education Buildings

HVAC System / Design OA Flow Rate	Minneapolis, MN 5 cfm	Minneapolis, MN 15 cfm	Washington, DC 5 cfm	Washington, DC 15 cfm	Miami, FL 5 cfm	Miami, FL 15 cfm
CV (FOAF)						
#5	100.0%	0.0%	100.0%	0.0%	100.0%	0.0%
6-10	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
11-15	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
16-19	0.0%	100.0%	0.0%	100.0%	0.0%	100.0%
$20	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CV (FOAF) Econ$_T$						
#5	67.5%	0.0%	73.3%	0.0%	92.6%	0.0%
6-10	18.9%	0.0%	12.4%	0.0%	0.4%	0.0%
11-15	4.0%	0.0%	3.9%	0.0%	0.8%	0.0%
16-19	2.3%	93.4%	2.9%	93.4%	0.7%	94.6%
$20	7.3%	6.6%	7.4%	6.6%	5.4%	5.4%
VAV (COA)						
#5	100.0%	0.0%	100.0%	0.0%	100.0%	0.0%
6-10	0.0%	0.0%	0.0%	46.2%	0.0%	0.0%
11-15	0.0%	76.8%	0.0%	23.7%	0.0%	12.8%
16-19	0.0%	23.2%	0.0%	30.0%	0.0%	87.2%
$20	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
VAV (COA) Econ$_T$						
#5	44.8%	0.0%	50.5%	0.0%	92.6%	0.0%
6-10	34.7%	0.0%	39.8%	46.2%	0.4%	0.0%
11-15	19.1%	76.8%	9.3%	23.7%	4.4%	12.8%
16-19	1.2%	23.0%	0.4%	30.0%	1.9%	86.4%
$20	0.2%	0.2%	0.0%	0.0%	0.8%	0.8%

Exhibit 4 (cont.)
Percent of Occupied Hours Air Flows are Achieved for Assembly Buildings

HVAC System / Design OA Flow Rate	Minneapolis, MN 5 cfm	Minneapolis, MN 15 cfm	Washington, DC 5 cfm	Washington, DC 15 cfm	Miami, FL 5 cfm	Miami, FL 15 cfm
CV (FOAF)						
#5	100.0%	0.0%	100.0%	0.0%	100.0%	0.0%
6-10	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
11-15	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
16-19	0.0%	100.0%	0.0%	100.0%	0.0%	100.0%
$20	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CV (FOAF) Econ$_T$						
#5	61.8%	0.0%	76.8%	0.0%	91.2%	0.0%
6-10	30.1%	0.0%	13.1%	0.0%	0.9%	0.0%
11-15	3.6%	0.0%	3.3%	0.0%	1.4%	0.0%
16-19	1.6%	97.1%	2.1%	95.3%	1.3%	94.7%
$20	3.0%	2.9%	4.7%	4.7%	5.2%	5.3%
VAV (COA)						
#5	100.0%	0.0%	100.0%	0.0%	100.0%	0.0%
6-10	0.0%	78.5%	0.0%	69.8%	0.0%	8.5%
11-15	0.0%	17.8%	0.0%	22.5%	0.0%	37.0%
16-19	0.0%	3.7%	0.0%	7.8%	0.0%	54.5%
$20	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
VAV (COA) Econ$_T$						
#5	68.4%	0.0%	69.9%	0.0%	91.1%	0.0%
6-10	29.2%	78.5%	26.4%	69.8%	3.8%	8.5%
11-15	2.4%	17.8%	3.6%	22.5%	4.8%	37.0%
16-19	0.0%	3.7%	0.1%	7.8%	0.4%	54.5%
$20	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Exhibit 5
VAV Box Minimum Settings Necessary to Guarantee 15 cfm/person During All Occupied Hours (Percent of Peak Zone Supply Air Flow)

Building Type / Zone	Minneapolis, MN	Washington, DC	Miami, FL
Education			
Core	71.0%	68.4%	53.7%
East	39.4%	45.1%	37.8%
North	53.6%	55.5%	43.8%
West	48.5%	52.2%	43.4%
South	47.1%	51.1%	42.6%
Assembly			
Core	100.0%	100.0%	95.0%
East	38.9%	65.1%	46.5%
North	40.7%	41.8%	62.7%
West	42.0%	57.4%	52.7%
South	43.8%	52.3%	54.1%

Exhibit 6
Percent of Occupied Hours Outdoor Air Flow Rates are Achieved with and without VAV Box Adjustments at a Design Setting of 15 cfm/person

Building	Minneapolis, MN		Washington, DC		Miami, FL	
HVAC System	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted
Education						
VAV (COA)						
#5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6-10	0.0%	0.0%	46.2%	0.0%	0.0%	0.0%
11-15	76.8%	0.0%	23.7%	0.0%	12.8%	0.0%
16-19	23.2%	100.0%	30.0%	100.0%	87.2%	100.0%
$20	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
VAV (COA) Econ$_T$						
#5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6-10	0.0%	0.0%	46.2%	0.0%	0.0%	0.0%
11-15	76.8%	0.0%	23.7%	0.0%	12.8%	0.0%
16-19	23.0%	99.4%	30.0%	100.0%	86.4%	98.9%
$20	0.2%	0.6%	0.0%	0.0%	0.8%	1.1%
Assembly						
VAV (COA)						
#5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6-10	78.5%	0.0%	69.8%	0.0%	8.5%	0.0%
11-15	17.8%	0.0%	22.5%	0.0%	37.0%	0.0%
16-19	3.7%	100.0%	7.8%	100.0%	54.5%	100.0%
$20	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
VAV (COA) Econ$_T$						
#5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6-10	78.5%	0.0%	69.8%	0.0%	8.5%	0.0%
11-15	17.8%	0.0%	22.5%	0.0%	37.0%	0.0%
16-19	3.7%	100.0%	7.8%	100.0%	54.5%	100.0%
$20	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Exhibit 7
Supply Volume and Outdoor Air Fractions for 5 and 15 cfm Outddor Air per person at Design and Minimum Load Conditions

Building	Minneapolis, MN				Washington, DC				Miami, FL			
	Supply Volume		OA Fraction		Supply Volume		OA Fraction		Supply Volume		OA Fraction	
HVAC System	5 cfm	15 cfm	5 cfm	15 cfm	5 cfm	15 cfm	5 cfm	15 cfm	5 cfm	15 cfm	5 cfm	15 cfm
Education												
CV (FOAF)												
Design Load	53684	53684	0.140	0.419	45123	45123	0.161	0.484	50944	50944	0.143	0.428
Minimum Load	53684	53684	0.140	0.419	45123	45123	0.161	0.484	50944	50944	0.143	0.428
VAV (COA)												
Design Load	53684	53684	0.140	0.419	45123	45123	0.161	0.484	50944	50944	0.143	0.428
Minimum Load	16105	22478	0.465	1.000	13537	21823	0.537	1.000	15283	21823	0.476	1.000
Assembly												
CV (FOAF)												
Design Load	26185	26185	0.216	0.647	23415	23415	0.234	0.703	22496	22496	0.244	0.732
Minimum Load	26185	26185	0.216	0.647	23415	23415	0.234	0.703	22496	22496	0.244	0.732
VAV (COA)												
Design Load	26185	26185	0.216	0.647	22100	22100	0.248	0.745	22496	22496	0.244	0.732
Minimum Load	7856	16955	0.719	1.000	6630	16461	0.828	1.000	6749	16461	0.813	1.000

Exhibit 8
Percent of Occupied Hours with Specified Indoor Air Temperatures for Education Buildings

HVAC System	Minneapolis, MN		Washington, DC		Miami, FL	
Temperature	5 cfm	15 cfm	5 cfm	15 cfm	5 cfm	15 cfm
CV (FOAF)						
70	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
71-74	88.4%	89.7%	78.0%	78.8%	4.8%	6.3%
75-79	11.6%	10.3%	22.0%	21.2%	95.2%	93.7%
79	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CV (FOAF) $Econ_T$						
70	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
71-74	88.4%	89.7%	78.0%	78.8%	4.8%	6.4%
75-79	11.6%	10.3%	22.0%	21.2%	95.2%	93.6%
79	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
VAV (COA)						
70	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
71-74	76.8%	76.9%	58.8%	59.0%	1.8%	2.1%
75-79	23.2%	23.1%	41.2%	41.0%	98.2%	97.9%
79	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
VAV (COA) $Econ_T$						
70	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
71-74	77.0%	76.9%	59.1%	59.0%	2.0%	2.1%
75-79	23.0%	23.1%	40.9%	41.0%	98.0%	97.9%
79	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Exhibit 8 (cont.)
Percent of Occupied Hours with Specified Indoor Air Temperatures for Assembly Buildings

HVAC System	Minneapolis, MN		Washington, DC		Miami, FL	
Temperature	5 cfm	15 cfm	5 cfm	15 cfm	5 cfm	15 cfm
CV (FOAF)						
70	2.9%	2.9%	2.5%	2.6%	0.0%	0.0%
71-74	57.8%	66.5%	41.6%	51.6%	0.5%	2.1%
75-79	39.4%	30.6%	55.9%	45.8%	99.1%	97.5%
79	0.0%	0.0%	0.0%	0.0%	0.3%	0.3%
CV (FOAF) $Econ_T$						
70	2.9%	2.9%	2.5%	2.6%	0.0%	0.0%
71-74	58.0%	66.6%	41.8%	51.7%	0.5%	2.2%
75-79	39.1%	30.6%	55.6%	45.7%	99.1%	97.5%
79	0.0%	0.0%	0.0%	0.0%	0.3%	0.3%
VAV (COA)						
70	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
71-74	68.7%	69.3%	49.2%	49.6%	0.6%	0.7%
75-79	31.3%	30.7%	50.8%	50.4%	99.2%	97.6%
79	0.0%	0.0%	0.0%	0.0%	0.2%	1.7%
VAV (COA) $Econ_T$						
70	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
71-74	68.9%	69.3%	49.4%	49.6%	0.7%	0.7%
75-79	31.1%	30.7%	50.6%	50.4%	99.1%	97.6%
79	0.0%	0.0%	0.0%	0.0%	0.2%	1.7%

Exhibit 9
Percent of Occupied Hours with Specified Indoor Relative Humidity for Education Buildings

HVAC System	Minneapolis, MN		Washington, DC		Miami, FL	
Relative Humidity	5 cfm	15 cfm	5 cfm	15 cfm	5 cfm	15 cfm
CV (FOAF)						
<20%	11.7%	19.3%	7.4%	12.5%	0.2%	0.4%
21-29%	11.8%	19.5%	7.8%	12.3%	1.0%	1.2%
30-50%	34.3%	43.1%	30.6%	40.6%	27.3%	21.0%
51-60%	23.7%	13.8%	28.6%	24.2%	52.7%	51.4%
61-70%	13.7%	3.9%	17.1%	9.9%	18.3%	25.2%
>70%	4.9%	0.3%	8.5%	0.6%	0.5%	0.9%
CV (FOAF) Econ$_T$						
<20%	12.1%	19.3%	8.0%	12.7%	0.5%	0.4%
21-29%	13.1%	20.0%	9.6%	12.7%	1.6%	1.5%
30-50%	36.2%	43.0%	32.7%	40.0%	27.3%	20.9%
51-60%	21.5%	13.5%	26.8%	24.2%	51.9%	50.9%
61-70%	12.5%	3.9%	15.5%	9.6%	18.2%	25.3%
>70%	4.6%	0.3%	7.5%	0.8%	0.5%	0.9%
VAV (COA)						
<20%	12.7%	18.5%	8.3%	11.5%	0.1%	0.4%
21-29%	11.2%	15.6%	7.5%	9.2%	0.9%	1.3%
30-50%	26.9%	41.2%	24.1%	35.6%	14.8%	16.7%
51-60%	21.7%	14.7%	22.5%	24.3%	43.2%	38.5%
61-70%	17.4%	7.7%	20.4%	14.6%	32.7%	35.4%
>70%	10.1%	2.3%	17.3%	4.9%	8.4%	7.6%
VAV (COA) Econ$_T$						
<20%	14.3%	18.5%	9.8%	11.5%	0.4%	0.4%
21-29%	12.4%	15.6%	8.9%	9.2%	1.2%	1.3%
30-50%	33.6%	41.2%	29.3%	35.6%	15.6%	16.7%
51-60%	22.4%	14.7%	23.0%	24.3%	42.8%	38.5%
61-70%	12.5%	7.6%	18.5%	14.6%	32.2%	35.4%
>70%	4.8%	2.3%	10.6%	4.9%	7.8%	7.6%

Exhibit 9 (cont.)
Percent of Occupied Hours with Specified Indoor Relative Humidity for Assembly Buildings

HVAC System	Minneapolis, MN		Washington, DC		Miami, FL	
Relative Humidity	5 cfm	15 cfm	5 cfm	15 cfm	5 cfm	15 cfm
CV (FOAF)						
<20%	9.1%	19.6%	5.8%	10.8%	0.1%	0.1%
21-29%	9.2%	19.4%	5.7%	15.1%	0.8%	1.2%
30-50%	32.1%	34.8%	24.6%	31.8%	16.3%	18.0%
51-60%	25.1%	15.9%	24.8%	19.7%	47.0%	52.8%
61-70%	18.6%	8.9%	28.4%	20.5%	35.6%	27.5%
>70%	5.9%	1.4%	10.8%	2.1%	0.3%	0.2%
CV (FOAF) $Econ_T$						
<20%	9.3%	19.6%	6.1%	11.1%	0.2%	0.2%
21-29%	9.4%	19.4%	6.5%	15.4%	1.2%	1.3%
30-50%	34.3%	35.0%	27.8%	31.6%	17.3%	18.3%
51-60%	24.3%	15.6%	25.2%	19.3%	45.9%	52.3%
61-70%	16.9%	8.9%	25.5%	20.3%	35.1%	27.7%
>70%	5.7%	1.5%	8.9%	2.2%	0.3%	0.2%
VAV (COA)						
<20%	10.1%	14.1%	7.0%	7.9%	0.1%	0.1%
21-29%	11.6%	14.2%	9.0%	11.0%	0.8%	1.1%
30-50%	31.6%	36.2%	25.4%	30.7%	11.0%	16.3%
51-60%	17.1%	17.5%	18.7%	22.0%	40.1%	51.2%
61-70%	16.2%	11.4%	23.0%	21.3%	44.1%	30.3%
>70%	13.4%	6.6%	17.0%	7.1%	3.9%	0.9%
VAV (COA) $Econ_T$						
<20%	10.2%	14.1%	7.1%	7.9%	0.1%	0.1%
21-29%	12.1%	14.2%	9.9%	11.0%	1.0%	1.1%
30-50%	34.7%	36.2%	27.2%	30.7%	12.4%	16.3%
51-60%	17.0%	17.5%	19.4%	22.0%	39.9%	51.2%
61-70%	15.2%	11.4%	22.3%	21.3%	42.8%	30.3%
>70%	10.8%	6.6%	14.1%	7.1%	3.9%	0.9%

Exhibit 10
Annual HVAC Energy Costs for Education Buildings at Alternative Outdoor Air Settings ($/sf)

HVAC System	Minneapolis, MN				Washington, DC				Miami, FL			
	5 cfm/ person	15 cfm/person			5 cfm/ person	15 cfm/person			5 cfm/ person	15 cfm/person		
		VAV Box Min 30%	Adjusted VAV Box			VAV Box Min 30%	Adjusted VAV Box			VAV Box Min 30%	Adjusted VAV Box	
End Use			No RH Control	RH Control			No RH Control	RH Control			No RH Control	RH Control
CV (FOAF)												
Fan	0.28	0.28		0.28	0.23	0.23		0.23	0.26	0.26		0.25
Cooling	0.41	0.47		0.52	0.45	0.53		0.55	0.71	0.84		0.88
Heating	0.23	0.44		0.46	0.08	0.18		0.20	0.00	0.00		0.01
Total	0.92	1.19		1.25	0.76	0.95		0.97	0.97	1.10		1.14
CV (FOAF) $Econ_T$												
Fan	0.28	0.28		0.28	0.23	0.23		0.23	0.26	0.26		0.25
Cooling	0.38	0.45		0.50	0.42	0.51		0.53	0.70	0.84		0.88
Heating	0.24	0.44		0.46	0.08	0.19		0.20	0.00	0.00		0.01
Total	0.89	1.17		1.24	0.73	0.93		0.96	0.96	1.10		1.14
VAV (COA)												
Fan	0.17	0.17	0.18	0.17	0.16	0.16	0.17	0.16	0.20	0.20	0.20	0.17
Cooling	0.39	0.41	0.42	0.43	0.43	0.49	0.50	0.52	0.64	0.75	0.76	0.79
Heating	0.32	0.42	0.51	0.52	0.14	0.17	0.25	0.26	0.00	0.00	0.00	0.01
Total	0.87	1.01	1.11	1.12	0.73	0.83	0.92	0.93	0.84	0.95	0.96	0.97
VAV (COA) $Econ_T$												
Fan	0.17	0.17	0.18	0.17	0.16	0.16	0.17	0.16	0.20	0.20	0.20	0.17
Cooling	0.35	0.41	0.42	0.43	0.40	0.49	0.50	0.51	0.64	0.75	0.76	0.79
Heating	0.32	0.42	0.51	0.52	0.14	0.17	0.25	0.26	0.00	0.00	0.00	0.01
Total	0.84	1.01	1.11	1.12	0.70	0.83	0.92	0.93	0.84	0.95	0.96	0.97

Exhibit 11
Annual HVAC Energy Costs for Assembly Buildings
at Alternative Outdoor Air Settings ($/sf)

HVAC System / End Use	Minneapolis, MN				Washington, DC				Miami, FL			
	5 cfm/ person	15 cfm/person			5 cfm/ person	15 cfm/person			5 cfm/ person	15 cfm/person		
		VAV Box Min 30%	Adjusted VAV Box			VAV Box Min 30%	Adjusted VAV Box			VAV Box Min 30%	Adjusted VAV Box	
			No RH Control	RH Control			No RH Control	RH Control			No RH Control	RH Control
CV (FOAF)												
Fan	0.41	0.41		0.42	0.36	0.36		0.39	0.34	0.34		0.34
Cooling	0.65	0.77		0.86	0.71	0.83		0.92	1.25	1.56		1.66
Heating	0.49	1.08		1.09	0.17	0.50		0.52	0.00	0.00		0.01
Total	1.55	2.26		2.37	1.24	1.70		1.83	1.60	1.90		2.01
CV (FOAF) $Econ_T$												
Fan	0.41	0.41		0.42	0.36	0.36		0.39	0.34	0.34		0.34
Cooling	0.58	0.73		0.82	0.64	0.79		0.89	1.23	1.55		1.66
Heating	0.50	1.08		1.10	0.18	0.51		0.53	0.00	0.00		0.01
Total	1.49	2.23		2.35	1.18	1.66		1.81	1.57	1.89		2.01
VAV (COA)												
Fan	0.24	0.27	0.30	0.29	0.23	0.25	0.29	0.28	0.29	0.30	0.33	0.30
Cooling	0.52	0.58	0.68	0.82	0.63	0.74	0.80	0.97	1.10	1.32	1.41	1.55
Heating	0.58	0.76	1.22	1.27	0.23	0.28	0.61	0.67	0.00	0.00	0.01	0.03
Total	1.34	1.62	2.20	2.38	1.10	1.27	1.71	1.92	1.40	1.62	1.74	1.88
VAV (COA) $Econ_T$												
Fan	0.24	0.27	0.30	0.29	0.23	0.25	0.29	0.28	0.29	0.30	0.33	0.30
Cooling	0.49	0.58	0.68	0.82	0.61	0.74	0.80	0.97	1.09	1.32	1.41	1.55
Heating	0.58	0.76	1.22	1.27	0.23	0.28	0.61	0.67	0.00	0.00	0.01	0.03
Total	1.31	1.62	2.20	2.38	1.07	1.27	1.71	1.92	1.39	1.62	1.74	1.88

Exhibit 12
Change in HVAC Energy Costs for Education Buildings
Due to Increased Outdoor Air Flow Rates from 5 to 15 cfm/person ($/sf)

HVAC System	Minneapolis, MN					Washington, DC					Miami, FL				
	5 cfm/ person	Difference 15-5 cfm/person				5 cfm/ person	Difference 15-5 cfm/person				5 cfm/ person	Difference 15-5 cfm/person			
		VAV Box Min 30%		Adjusted VAV Box			VAV Box Min 30%		Adjusted VAV Box			VAV Box Min 30%		Adjusted VAV Box	
End Use	($/sf)	($/sf)	(%)	($/sf)	(%)	($/sf)	($/sf)	(%)	($/sf)	(%)	($/sf)	($/sf)	(%)	($/sf)	(%)
CV (FOAF)															
Fan	0.28					0.23					0.26				
Cooling	0.41	0.06	14%			0.45	0.08	18%			0.71	0.13	19%		
Heating	0.23	0.21	90%			0.08	0.11	135%			0.00				
Total	0.92	0.27	29%			0.76	0.19	25%			0.97	0.13	14%		
CV (FOAF) $Econ_T$															
Fan	0.28					0.23					0.26				
Cooling	0.38	0.07	18%			0.42	0.09	23%			0.70	0.14	19%		
Heating	0.24	0.21	87%			0.08	0.10	130%			0.00				
Total	0.89	0.27	31%			0.73	0.20	27%			0.96	0.14	14%		
VAV (COA)															
Fan	0.17			0.01	5%	0.16			0.01	6%	0.20				
Cooling	0.39	0.03	8%	0.04	9%	0.43	0.06	15%	0.07	17%	0.64	0.11	17%	0.11	18%
Heating	0.32	0.10	32%	0.19	60%	0.14	0.03	25%	0.11	82%	0.00				
Total	0.87	0.13	15%	0.24	27%	0.73	0.10	14%	0.19	27%	0.84	0.11	14%	0.12	15%
VAV (COA) $Econ_T$															
Fan	0.17			0.01	5%	0.16			0.01	6%	0.20				
Cooling	0.35	0.06	18%	0.07	19%	0.40	0.09	22%	0.10	25%	0.64	0.11	18%	0.12	18%
Heating	0.32	0.10	31%	0.19	59%	0.14	0.03	24%	0.11	81%	0.00				
Total	0.84	0.16	19%	0.27	32%	0.70	0.12	18%	0.22	31%	0.84	0.12	14%	0.13	15%

Exhibit 13
Change in HVAC Energy Costs for Assembly Buildings
Due to Increased Outdoor Air Flow Rates from 5 to 15 cfm/person ($/sf)

Building Configuration	Minneapolis, MN					Washington, DC					Miami, FL				
	5 cfm/ person	Difference 15-5 cfm/person				5 cfm/ person	Difference 15-5 cfm/person				5 cfm/ person	Difference 15-5 cfm/person			
		VAV Box Min 30%		Adjusted VAV Box			VAV Box Min 30%		Adjusted VAV Box			VAV Box Min 30%		Adjusted VAV Box	
End Use	($/sf)	($/sf)	(%)	($/sf)	(%)	($/sf)	($/sf)	(%)	($/sf)	(%)	($/sf)	($/sf)	(%)	($/sf)	(%)
CV (FOAF)															
Fan	0.41					0.36					0.34				
Cooling	0.65	0.12	18%			0.71	0.12	17%			1.25	0.30	24%		
Heating	0.49	0.59	121%			0.17	0.33	197%			0.00				
Total	1.55	0.71	46%			1.24	0.45	36%			1.60	0.31	19%		
CV (FOAF) $Econ_T$															
Fan	0.41					0.36					0.34				
Cooling	0.58	0.15	26%			0.64	0.15	24%			1.23	0.32	26%		
Heating	0.50	0.58	118%			0.18	0.33	184%			0.00				
Total	1.49	0.74	50%			1.18	0.48	41%			1.57	0.32	20%		
VAV (COA)															
Fan	0.24	0.03	14%	0.06	24%	0.23	0.02	9%	0.06	26%	0.29	0.01	2%	0.03	11%
Cooling	0.52	0.07	13%	0.16	30%	0.63	0.10	17%	0.17	28%	1.10	0.21	19%	0.30	28%
Heating	0.58	0.18	31%	0.64	111%	0.23	0.05	20%	0.38	162%	0.00			0.01	807%
Total	1.34	0.28	21%	0.86	64%	1.10	0.17	16%	0.61	56%	1.40	0.22	16%	0.35	25%
VAV (COA) $Econ_T$															
Fan	0.24	0.03	14%	0.06	24%	0.23	0.02	9%	0.06	26%	0.29	0.01	2%	0.03	11%
Cooling	0.49	0.09	19%	0.18	37%	0.61	0.13	21%	0.20	33%	1.09	0.22	20%	0.31	29%
Heating	0.58	0.18	31%	0.64	111%	0.23	0.05	20%	0.38	162%	0.00			0.01	786%
Total	1.31	0.30	23%	0.88	67%	1.07	0.20	18%	0.64	60%	1.39	0.23	16%	0.36	26%

Exhibit 14
Utility Price Sensitivity of Annual HVAC Energy Costs for Education Buildings ($/sf)

HVAC System / Utility Option	Minneapolis, MN				Washington, DC				Miami, FL			
	5 cfm/ person	15 cfm/person			5 cfm/ person	15 cfm/person			5 cfm/ person	15 cfm/person		
		w/RH Control	Difference (15-5)			w/RH Control	Difference (15-5)			w/RH Control	Difference (15-5)	
			($/sf)	(%)			($/sf)	(%)			($/sf)	(%)
CV (FOAF)												
Base Price	0.92	1.25	0.33	36%	0.76	0.97	0.22	28%	0.97	1.14	0.17	17%
Option 1	1.00	1.27	0.27	27%	0.89	1.08	0.19	21%	1.22	1.44	0.21	17%
Option 2	0.84	1.24	0.39	47%	0.63	0.87	0.24	38%	0.72	0.84	0.13	17%
Option 3	1.08	1.45	0.37	34%	0.91	1.16	0.25	27%	1.16	1.35	0.20	17%
Option 4	0.76	1.05	0.29	38%	0.60	0.78	0.18	30%	0.78	0.93	0.14	18%
CV (FOAF) Econ$_T$												
Base Price	0.89	1.24	0.35	39%	0.73	0.96	0.23	32%	0.96	1.14	0.18	18%
Option 1	0.95	1.24	0.29	30%	0.84	1.06	0.21	25%	1.21	1.43	0.22	18%
Option 2	0.83	1.23	0.40	49%	0.61	0.87	0.26	41%	0.71	0.84	0.13	18%
Option 3	1.05	1.44	0.39	37%	0.89	1.15	0.27	30%	1.14	1.35	0.20	18%
Option 4	0.73	1.04	0.30	42%	0.57	0.77	0.20	35%	0.77	0.92	0.15	19%
VAV (COA)												
Base Price	0.87	1.12	0.25	28%	0.73	0.93	0.21	28%	0.84	0.97	0.13	15%
Option 1	0.88	1.07	0.18	21%	0.80	0.98	0.18	22%	1.05	1.20	0.15	15%
Option 2	0.86	1.18	0.31	36%	0.65	0.89	0.24	36%	0.64	0.74	0.10	16%
Option 3	1.01	1.28	0.27	26%	0.88	1.11	0.23	27%	1.02	1.17	0.16	15%
Option 4	0.73	0.96	0.23	31%	0.58	0.75	0.18	31%	0.66	0.76	0.10	15%
VAV (COA) Econ$_T$												
Base Price	0.84	1.12	0.28	33%	0.70	0.93	0.23	33%	0.84	0.97	0.13	16%
Option 1	0.84	1.07	0.23	27%	0.77	0.98	0.21	28%	1.04	1.20	0.16	15%
Option 2	0.85	1.18	0.33	38%	0.64	0.89	0.25	39%	0.63	0.74	0.11	17%
Option 3	0.98	1.28	0.30	30%	0.85	1.11	0.26	30%	1.01	1.17	0.16	16%
Option 4	0.70	0.96	0.26	37%	0.55	0.75	0.20	37%	0.66	0.76	0.10	16%

Exhibit 15
Utility Price Sensitivity of Annual HVAC Energy Costs for Assembly Buildings ($/sf)

HVAC System / Utility Option	Minneapolis, MN				Washington, DC				Miami, FL			
	5 cfm/ person	15 cfm/person			5 cfm/ person	15 cfm/person			5 cfm/ person	15 cfm/person		
		w/RH Control	Difference (15-5)			w/RH Control	Difference (15-5)			w/RH Control	Difference (15-5)	
			($/sf)	(%)			($/sf)	(%)			($/sf)	(%)
CV (FOAF)												
Base Price	1.55	2.37	0.82	53%	1.24	1.83	0.59	47%	1.60	2.01	0.42	26%
Option 1	1.64	2.28	0.63	39%	1.45	1.95	0.49	34%	2.05	2.56	0.51	25%
Option 2	1.46	2.46	1.01	69%	1.03	1.71	0.68	66%	1.14	1.46	0.33	29%
Option 3	1.78	2.69	0.91	51%	1.46	2.14	0.68	47%	1.85	2.37	0.51	28%
Option 4	1.32	2.05	0.73	55%	1.02	1.52	0.49	48%	1.34	1.66	0.32	24%
CV (FOAF) $Econ_T$												
Base Price	1.49	2.35	0.86	58%	1.18	1.81	0.63	53%	1.57	2.01	0.43	27%
Option 1	1.55	2.23	0.69	44%	1.36	1.91	0.55	40%	2.02	2.55	0.53	26%
Option 2	1.43	2.46	1.03	72%	1.00	1.71	0.71	71%	1.13	1.46	0.34	30%
Option 3	1.72	2.67	0.95	55%	1.40	2.13	0.72	52%	1.83	2.36	0.53	29%
Option 4	1.26	2.02	0.77	61%	0.96	1.50	0.54	56%	1.32	1.65	0.34	26%
VAV (COA)												
Base Price	1.34	2.38	1.04	78%	1.10	1.92	0.82	75%	1.40	1.88	0.48	35%
Option 1	1.31	2.20	0.89	68%	1.21	1.98	0.77	64%	1.79	2.39	0.60	34%
Option 2	1.36	2.56	1.20	88%	0.98	1.85	0.87	88%	1.01	1.37	0.37	36%
Option 3	1.52	2.65	1.13	74%	1.30	2.21	0.90	69%	1.64	2.20	0.56	34%
Option 4	1.15	2.11	0.96	83%	0.89	1.63	0.74	83%	1.16	1.57	0.41	35%
VAV (COA) $Econ_T$												
Base Price	1.31	2.38	1.07	81%	1.07	1.92	0.85	79%	1.39	1.88	0.49	36%
Option 1	1.28	2.20	0.93	73%	1.17	1.98	0.81	69%	1.77	2.39	0.61	35%
Option 2	1.35	2.56	1.21	90%	0.97	1.85	0.88	91%	1.00	1.37	0.37	37%
Option 3	1.50	2.65	1.16	77%	1.28	2.21	0.93	72%	1.63	2.20	0.57	35%
Option 4	1.13	2.11	0.98	87%	0.87	1.63	0.77	89%	1.15	1.57	0.42	36%

Exhibit 16

HVAC System Peak Coil Loads for Education Buildings at Alternative Outdoor Air Settings (kBTU/Hr)

HVAC System	Minneapolis, MN				Washington, DC				Miami, FL			
	5 cfm/ person	15 cfm/person			5 cfm/ person	15 cfm/person			5 cfm/ person	15 cfm/person		
		VAV Box Min 30%	Adjusted VAV Box			VAV Box Min 30%	Adjusted VAV Box			VAV Box Min 30%	Adjusted VAV Box	
Coil			No RH Control	RH Control			No RH Control	RH Control			No RH Control	RH Control
CV (FOAF)												
Cooling	2068	2478		2747	2071	2594		2633	2409	3030		2912
Heating	2459	3197		3197	1818	2118		2118	17	536		598
Preheat	0	683		683	0	183		183	0	0		0
CV (FOAF) Econ$_T$												
Cooling	2068	2478		2747	2071	2594		2633	2409	3030		2912
Heating	2609	3197		3197	1884	2118		2118	17	536		580
Preheat	0	683		683	0	183		183	0	0		0
VAV (COA)												
Cooling	1841	2211	2211	2210	1951	2453	2439	2421	2213	2785	2742	2760
Heating	2819	2819	2820	2820	1935	1981	2027	2027	391	464	668	669
Preheat	246	1344	1528	1528	90	521	840	840	0	140	200	200
VAV (COA) Econ$_T$												
Cooling	1841	2211	2211	2210	1951	2453	2439	2421	2213	2785	2742	2760
Heating	2819	2819	2820	2820	1935	1981	2027	2027	397	464	668	670
Preheat	246	1344	1528	1528	90	521	840	840	0	140	200	200

Exhibit 17
HVAC System Peak Coil Loads for Assembly Buildings at Alternative Outdoor Air Settings (kBTU/Hr)

HVAC System	Minneapolis, MN				Washington, DC				Miami, FL			
	5 cfm/ person	15 cfm/person			5 cfm/ person	15 cfm/person			5 cfm/ person	15 cfm/person		
		VAV Box Min 30%	Adjusted VAV Box			VAV Box Min 30%	Adjusted VAV Box			VAV Box Min 30%	Adjusted VAV Box	
Coil			No RH Control	RH Control			No RH Control	RH Control			No RH Control	RH Control
CV (FOAF)												
Cooling	1193	1568		1720	1144	1491		1679	1394	1838		2005
Heating	1449	1517		1517	1009	1227		1227	61	541		542
Preheat	0	1097		1097	0	577		577	0	0		0
CV (FOAF) Econ$_T$												
Cooling	1193	1568		1720	1157	1505		1679	1394	1838		2005
Heating	1476	1517		1517	1153	1303		1227	63	541		542
Preheat	0	1097		1097	0	577		577	0	0		0
VAV (COA)												
Cooling	958	1161	1230	1511	1067	1360	1342	1599	1229	1575	1577	1738
Heating	1134	1151	1240	1240	822	868	999	999	96	109	390	391
Preheat	330	1090	1249	1249	224	409	777	777	0	84	151	151
VAV (COA) Econ$_T$												
Cooling	958	1161	1230	1511	1067	1360	1342	1599	1229	1575	1577	1738
Heating	1134	1151	1240	1240	822	868	999	999	99	109	390	391
Preheat	330	1090	1249	1249	224	409	777	777	0	84	151	151

Exhibit 18
Change in HVAC System Peak Coil Loads for Education Buildings
Due to Increased Outdoor Air Flow Rates from 5 to 15 cfm/person

HVAC System	Minneapolis, MN					Washington, DC					Miami, FL				
	5 cfm/ person	Difference 15-5 cfm/person				5 cfm/ person	Difference 15-5 cfm/person				5 cfm/ person	Difference 15-5 cfm/person			
		VAV Box Min 30%		Adjusted VAV Box			VAV Box Min 30%		Adjusted VAV Box			VAV Box Min 30%		Adjusted VAV Box	
Coil	(kBTU/ Hr)	(kBtu/ Hr)	(%)	(kBtu/ Hr)	(%)	(kBtu/ Hr)	(kBtu/ Hr)	(%)	(kBtu/ Hr)	(%)	(kBtu/ Hr)	(kBtu/ Hr)	(%)	(kBtu/ Hr)	(%)
CV (FOAF)															
Cooling	2068	410	20%			2071	524	25%			2409	622	26%		
Heating	2459	737	30%			1818	300	17%			17	519	3118%		
Preheat	0	683	Increase			0	183	Increase			0				
CV (FOAF) Econ$_T$															
Cooling	2068	410	20%			2071	524	25%			2409	622	26%		
Heating	2609	588	23%			1884	234	12%			17	520	3124%		
Preheat	0	683	Increase			0	183	Increase			0				
VAV (COA)															
Cooling	1841	370	20%	370	20%	1951	502	26%	488	25%	2213	571	26%	529	24%
Heating	2819			1		1935	46	2%	93	5%	391	73	19%	277	71%
Preheat	246	1098	447%	1282	521%	90	431	478%	750	832%	0	140	Increase	200	Increase
VAV (COA) Econ$_T$															
Cooling	1841	370	20%	370	20%	1951	502	26%	488	25%	2213	571	26%	529	24%
Heating	2819			1		1935	46	2%	93	5%	397	67	17%	271	68%
Preheat	246	1098	447%	1282	521%	90	431	478%	750	832%	0	140	Increase	200	Increase

Exhibit 19
Change in HVAC System Peak Coil Loads for Assembly Buildings
Due to Increased Outdoor Air Flow Rates from 5 to 15 cfm/person

HVAC System	Minneapolis, MN					Washington, DC					Miami, FL				
	5 cfm/person	Difference 15-5 cfm/person				5 cfm/person	Difference 15-5 cfm/person				5 cfm/person	Difference 15-5 cfm/person			
		VAV Box Min 30%		Adjusted VAV Box			VAV Box Min 30%		Adjusted VAV Box			VAV Box Min 30%		Adjusted VAV Box	
Coil	(kBtu/Hr)	(kBtu/Hr)	(%)	(kBtu/Hr)	(%)	(kBtu/Hr)	(kBtu/Hr)	(%)	(kBtu/Hr)	(%)	(kBtu/Hr)	(kBtu/Hr)	(%)	(kBtu/Hr)	(%)
CV (FOAF)															
Cooling	1193	375	31%			1144	347	30%			1394	444	32%		
Heating	1449	68	5%			1009	218	22%			61	480	791%		
Preheat	0	1097	Increase			0	577	Increase			0				
CV (FOAF) $Econ_T$															
Cooling	1193	375	31%			1157	348	30%			1394	444	32%		
Heating	1476	41	3%			1153	149	13%			63	478	758%		
Preheat	0	1097	Increase			0	577	Increase			0				
VAV (COA)															
Cooling	958	203	21%	271	28%	1067	293	27%	275	26%	1229	346	28%	349	28%
Heating	1134	17	1%	106	9%	822	46	6%	177	22%	96	13	13%	294	306%
Preheat	330	760	230%	919	279%	224	185	83%	553	247%	0	84	Increase	151	Increase
VAV (COA) $Econ_T$															
Cooling	958	203	21%	271	28%	1067	293	27%	275	26%	1229	346	28%	349	28%
Heating	1134	17	1%	106	9%	822	46	6%	177	22%	99	10	10%	291	293%
Preheat	330	760	230%	919	279%	224	185	83%	553	247%	0	84	Increase	151	Increase

Exhibit 20
Annual HVAC Energy Cost Impacts with and without Sensible Heat Recovery for Education Buildings

HVAC System	Minneapolis, MN					Washington, DC					Miami, FL				
	5 cfm/person	15 cfm/person w/RH Control				5 cfm/person	15 cfm/person w/RH Control				5 cfm/person	15 cfm/person w/RH Control			
		without Heat Recovery		with Heat Recovery			without Heat Recovery		with Heat Recovery			without Heat Recovery		with Heat Recovery	
End Use	($/sf)	($/sf)	(%)	($/sf)	(%)	($/sf)	($/sf)	(%)	($/sf)	(%)	($/sf)	($/sf)	(%)	($/sf)	(%)
CV (FOAF)															
Fan	0.28	0.28		0.28		0.23	0.23		0.23		0.26	0.25	-3%	0.25	-3%
Cooling	0.41	0.52	27%	0.52	27%	0.45	0.55	22%	0.55	22%	0.71	0.88	24%	0.88	24%
Heating	0.23	0.46	95%	0.44	90%	0.08	0.20	149%	0.19	148%	0.00	0.01	79273%	0.01	77670%
Total	0.92	1.25	36%	1.24	35%	0.76	0.97	28%	0.97	28%	0.97	1.14	17%	1.14	17%
CV (FOAF) Econ$_T$															
Fan	0.28	0.28		0.28		0.23	0.23		0.23		0.26	0.25	-3%	0.25	-3%
Cooling	0.38	0.50	32%	0.50	32%	0.42	0.53	27%	0.53	27%	0.70	0.88	25%	0.88	25%
Heating	0.24	0.46	95%	0.45	90%	0.08	0.20	150%	0.20	148%	0.00	0.01	87489%	0.01	85877%
Total	0.89	1.24	39%	1.22	37%	0.73	0.96	32%	0.96	32%	0.96	1.14	18%	1.14	18%
VAV (COA)															
Fan	0.17	0.17		0.17		0.16	0.16		0.16		0.20	0.17	-12%	0.17	-12%
Cooling	0.39	0.43	12%	0.43	12%	0.43	0.52	20%	0.52	20%	0.64	0.79	22%	0.79	22%
Heating	0.32	0.52	63%	0.42	31%	0.14	0.26	92%	0.23	70%	0.00	0.01	1036%	0.01	1024%
Total	0.87	1.12	28%	1.02	16%	0.73	0.93	28%	0.90	24%	0.84	0.97	15%	0.97	15%
VAV (COA) Econ$_T$															
Fan	0.17	0.17		0.17		0.16	0.16		0.16		0.20	0.17	-12%	0.17	-12%
Cooling	0.35	0.43	22%	0.43	22%	0.40	0.51	28%	0.51	28%	0.64	0.79	23%	0.79	23%
Heating	0.32	0.52	62%	0.42	30%	0.14	0.26	90%	0.23	69%	0.00	0.01	978%	0.01	967%
Total	0.84	1.12	33%	1.02	21%	0.70	0.93	33%	0.90	29%	0.84	0.97	16%	0.97	16%

Exhibit 21
Annual HVAC Energy Cost Impacts with and without Sensible Heat Recovery for Assembly Buildings

HVAC System	Minneapolis, MN					Washington, DC					Miami, FL				
	5 cfm/ person	15 cfm/person w/RH Control				5 cfm/ person	15 cfm/person w/RH Control				5 cfm/ person	15 cfm/person w/RH Control			
		without Heat Recovery		with Heat Recovery			without Heat Recovery		with Heat Recovery			without Heat Recovery		with Heat Recovery	
End Use	($/sf)	($/sf)	(%)	($/sf)	(%)	($/sf)	($/sf)	(%)	($/sf)	(%)	($/sf)	($/sf)	(%)	($/sf)	(%)
CV (FOAF)															
Fan	0.41	0.42	2%	0.42	2%	0.36	0.39	8%	0.39	8%	0.34	0.34		0.34	
Cooling	0.65	0.86	31%	0.86	31%	0.71	0.92	30%	0.92	30%	1.25	1.66	33%	1.66	33%
Heating	0.49	1.09	124%	0.89	83%	0.17	0.52	207%	0.47	175%	0.00	0.01	2016%	0.01	1991%
Total	1.55	2.37	53%	2.17	40%	1.24	1.83	47%	1.78	43%	1.60	2.01	26%	2.01	26%
CV (FOAF) $Econ_T$															
Fan	0.41	0.42	2%	0.42	2%	0.36	0.39	8%	0.39	8%	0.34	0.34		0.34	
Cooling	0.58	0.82	41%	0.82	41%	0.64	0.89	39%	0.89	39%	1.23	1.66	34%	1.66	34%
Heating	0.50	1.10	123%	0.90	82%	0.18	0.53	199%	0.48	169%	0.00	0.01	801%	0.01	792%
Total	1.49	2.35	58%	2.14	44%	1.18	1.81	53%	1.76	49%	1.57	2.01	27%	2.01	27%
VAV (COA)															
Fan	0.24	0.29	22%	0.29	22%	0.23	0.28	20%	0.28	20%	0.29	0.30		0.30	
Cooling	0.52	0.82	57%	0.82	57%	0.63	0.97	54%	0.97	54%	1.10	1.55	41%	1.55	41%
Heating	0.58	1.27	120%	0.90	55%	0.23	0.67	187%	0.54	129%	0.00	0.03	2102%	0.03	2034%
Total	1.34	2.38	78%	2.00	50%	1.10	1.92	75%	1.78	63%	1.40	1.88	35%	1.88	35%
VAV (COA) $Econ_T$															
Fan	0.24	0.29	22%	0.29	22%	0.23	0.28	20%	0.28	20%	0.29	0.30		0.30	
Cooling	0.49	0.82	66%	0.82	66%	0.61	0.97	60%	0.97	60%	1.09	1.55	42%	1.55	42%
Heating	0.58	1.27	120%	0.90	54%	0.23	0.67	186%	0.54	129%	0.00	0.03	2047%	0.03	1984%
Total	1.31	2.38	81%	2.00	53%	1.07	1.92	79%	1.78	66%	1.39	1.88	36%	1.88	35%

Exhibit 22
Effect of Sensible Heat Recovery on HVAC System Peak Coil Loads for Education Buildings

HVAC System	Minneapolis, MN					Washington, DC					Miami, FL				
	5 cfm/person	15 cfm/person w/RH Control				5 cfm/person	15 cfm/person w/RH Control				5 cfm/person	15 cfm/person w/RH Control			
		without Heat Recovery		with Heat Recovery			without Heat Recovery		with Heat Recovery			without Heat Recovery		with Heat Recovery	
Coil	(kBtu/Hr)	(kBtu/Hr)	(%)	(kBtu/Hr)	(%)	(kBtu/Hr)	(kBtu/Hr)	(%)	(kBtu/Hr)	(%)	(kBtu/Hr)	(kBtu/Hr)	(%)	(kBtu/Hr)	(%)
CV (FOAF)															
Cooling	2068	2747	33%	2747	33%	2071	2633	27%	2633	27%	2409	2912	21%	2912	21%
Heating	2459	3197	30%	3197	30%	1818	2118	17%	2118	17%	17	598	3488%	594	3468%
Preheat	0	683	Increase	0		0	183	Increase	0		0	0		0	
CV (FOAF) Econ$_T$															
Cooling	2068	2747	33%	2747	33%	2071	2633	27%	2633	27%	2409	2912	21%	2912	21%
Heating	2609	3197	23%	3197	23%	1884	2118	12%	2118	12%	17	580	3387%	577	3366%
Preheat	0	683	Increase	0		0	183	Increase	77	Increase	0	0		0	
VAV (COA)															
Cooling	1841	2210	20%	2210	20%	1951	2421	24%	2421	24%	2213	2760	25%	2760	25%
Heating	2819	2820		2820		1935	2027	5%	2027	5%	391	669	71%	669	71%
Preheat	246	1528	521%	12	-95%	90	840	832%	3	-96%	0	200	Increase	0	
VAV (COA) Econ$_T$															
Cooling	1841	2210	20%	2210	20%	1951	2421	24%	2421	24%	2213	2760	25%	2760	25%
Heating	2819	2820		2820		1935	2027	5%	2027	5%	397	670	69%	670	69%
Preheat	246	1528	521%	12	-95%	90	840	832%	3	-96%	0	200	Increase	0	

Exhibit 23
Effect of Sensible Heat Recovery on HVAC System Peak Coil Loads for Assembly Buildings

HVAC System	Minneapolis, MN					Washington, DC					Miami, FL				
	5 cfm/person	15 cfm/person w/RH Control				5 cfm/person	15 cfm/person w/RH Control				5 cfm/person	15 cfm/person w/RH Control			
		without Heat Recovery		with Heat Recovery			without Heat Recovery		with Heat Recovery			without Heat Recovery		with Heat Recovery	
Coil	(kBtu/Hr)	(kBtu/Hr)	(%)	(kBtu/Hr)	(%)	(kBtu/Hr)	(kBtu/Hr)	(%)	(kBtu/Hr)	(%)	(kBtu/Hr)	(kBtu/Hr)	(%)	(kBtu/Hr)	(%)
CV (FOAF)															
Cooling	1193	1720	44%	1720	44%	1144	1679	47%	1679	47%	1394	2005	44%	2005	44%
Heating	1449	1517	5%	1517	5%	1009	1227	22%	1227	22%	61	542	793%	541	790%
Preheat	0	1097	Increase	0		0	577	Increase	0		0	0		0	
CV (FOAF) Econ$_T$															
Cooling	1193	1720	44%	1720	44%	1157	1679	45%	1679	45%	1394	2005	44%	2005	44%
Heating	1476	1517	3%	1517	3%	1153	1227	6%	1227	6%	63	542	760%	541	758%
Preheat	0	1097	Increase	44	Increase	0	577	Increase	38	Increase	0	0		0	
VAV (COA)															
Cooling	958	1511	58%	1511	58%	1067	1599	50%	1599	50%	1229	1738	41%	1738	41%
Heating	1134	1240	9%	1240	9%	822	999	22%	999	22%	96	391	306%	385	301%
Preheat	330	1249	279%	71	-79%	224	777	247%	4	-98%	0	151	Increase	0	
VAV (COA) Econ$_T$															
Cooling	958	1511	58%	1511	58%	1067	1599	50%	1599	50%	1229	1738	41%	1738	41%
Heating	1134	1240	9%	1240	9%	822	999	22%	999	22%	99	391	294%	386	289%
Preheat	330	1249	279%	71	-79%	224	777	247%	4	-98%	0	151	Increase	0	

Exhibit 24
Annual HVAC Energy Cost Impacts with and without Desiccant Dehumidification for Education Buildings

HVAC System	Minneapolis, MN					Washington, DC					Miami, FL				
	5 cfm/person ($/sf)	15 cfm/person w/RH Control				5 cfm/person ($/sf)	15 cfm/person w/RH Control				5 cfm/person ($/sf)	15 cfm/person w/RH Control			
		without Desiccant Dehumidification		with Desiccant Dehumidification			without Desiccant Dehumidification		with Desiccant Dehumidification			without Desiccant Dehumidification		with Desiccant Dehumidification	
End Use		($/sf)	(%)	($/sf)	(%)		($/sf)	(%)	($/sf)	(%)		($/sf)	(%)	($/sf)	(%)
CV (FOAF)															
Fan	0.28	0.28		0.34	22%	0.23	0.23		0.28	21%	0.26	0.25	-3%	0.32	25%
Cooling	0.41	0.52	27%	0.50	21%	0.45	0.55	22%	0.51	14%	0.71	0.88	24%	0.78	10%
Heating	0.23	0.44	90%	0.51	118%	0.08	0.19	148%	0.34	329%	0.00	0.01	77670%	0.14	1996414%
Total	0.92	1.24	35%	1.34	46%	0.76	0.97	28%	1.13	49%	0.97	1.14	17%	1.25	29%
CV (FOAF) Econ$_T$															
Fan	0.28	0.28		0.34	21%	0.23	0.23		0.28	20%	0.26	0.25	-3%	0.32	25%
Cooling	0.38	0.50	32%	0.48	27%	0.42	0.53	27%	0.50	20%	0.70	0.88	25%	0.78	12%
Heating	0.24	0.45	90%	0.50	111%	0.08	0.20	148%	0.31	291%	0.00	0.01	85877%	0.19	2664107%
Total	0.89	1.22	37%	1.32	48%	0.73	0.96	32%	1.09	50%	0.96	1.14	18%	1.29	35%
VAV (COA)															
Fan	0.17	0.17		0.22	33%	0.16	0.16		0.20	23%	0.20	0.17	-12%	0.25	25%
Cooling	0.39	0.43	12%	0.40	5%	0.43	0.52	20%	0.47	10%	0.64	0.79	22%	0.70	10%
Heating	0.32	0.42	31%	0.47	47%	0.14	0.23	70%	0.35	155%	0.00	0.01	1024%	0.17	22722%
Total	0.87	1.02	16%	1.10	26%	0.73	0.90	24%	1.02	40%	0.84	0.97	15%	1.12	33%
VAV (COA) Econ$_T$															
Fan	0.17	0.17		0.22	32%	0.16	0.16		0.20	22%	0.20	0.17	-12%	0.25	25%
Cooling	0.35	0.43	22%	0.41	17%	0.40	0.51	28%	0.49	20%	0.64	0.79	23%	0.71	11%
Heating	0.32	0.42	30%	0.46	43%	0.14	0.23	69%	0.33	139%	0.00	0.01	967%	0.16	19936%
Total	0.84	1.02	21%	1.10	30%	0.70	0.90	29%	1.01	44%	0.84	0.97	16%	1.11	33%

Exhibit 25
Annual HVAC Energy Cost Impacts with and without Desiccant Dehumidification for Assembly Buildings

HVAC System	Minneapolis, MN					Washington, DC					Miami, FL				
	5 cfm/person	15 cfm/person w/RH Control				5 cfm/person	15 cfm/person w/RH Control				5 cfm/person	15 cfm/person w/RH Control			
		without Desiccant Dehumidification		with Desiccant Dehumidification			without Desiccant Dehumidification		with Desiccant Dehumidification			without Desiccant Dehumidification		with Desiccant Dehumidification	
End Use	($/sf)	($/sf)	(%)	($/sf)	(%)	($/sf)	($/sf)	(%)	($/sf)	(%)	($/sf)	($/sf)	(%)	($/sf)	(%)
CV (FOAF)															
Fan	0.41	0.42	2%	0.51	24%	0.36	0.39	8%	0.44	22%	0.34	0.34		0.45	33%
Cooling	0.65	0.86	31%	0.82	25%	0.71	0.92	30%	0.85	20%	1.25	1.66	33%	1.47	17%
Heating	0.49	0.89	83%	1.10	125%	0.17	0.47	175%	0.84	393%	0.00	0.01	1991%	0.03	7181%
Total	1.55	2.17	40%	2.42	56%	1.24	1.78	43%	2.13	72%	1.60	2.01	26%	1.95	22%
CV (FOAF) Econ$_T$															
Fan	0.41	0.42	2%	0.51	24%	0.36	0.39	8%	0.44	22%	0.34	0.34		0.45	33%
Cooling	0.58	0.82	41%	0.78	35%	0.64	0.89	39%	0.83	29%	1.23	1.66	34%	1.46	18%
Heating	0.50	0.90	82%	1.09	119%	0.18	0.48	169%	0.81	353%	0.00	0.01	792%	0.03	3020%
Total	1.49	2.14	44%	2.38	60%	1.18	1.76	49%	2.07	75%	1.57	2.01	27%	1.94	24%
VAV (COA)															
Fan	0.24	0.29	22%	0.38	60%	0.23	0.28	20%	0.36	53%	0.29	0.30		0.40	36%
Cooling	0.52	0.82	57%	0.75	45%	0.63	0.97	54%	0.86	36%	1.10	1.55	41%	1.35	22%
Heating	0.58	0.90	55%	1.07	84%	0.23	0.54	129%	0.86	267%	0.00	0.03	2034%	0.17	11521%
Total	1.34	2.00	50%	2.20	65%	1.10	1.78	63%	2.07	89%	1.40	1.88	35%	1.92	38%
VAV (COA) Econ$_T$															
Fan	0.24	0.29	22%	0.38	60%	0.23	0.28	20%	0.35	52%	0.29	0.30		0.40	37%
Cooling	0.49	0.82	66%	0.76	54%	0.61	0.97	60%	0.87	44%	1.09	1.55	42%	1.35	23%
Heating	0.58	0.90	54%	1.06	82%	0.23	0.54	129%	0.83	254%	0.00	0.03	1984%	0.17	11218%
Total	1.31	2.00	53%	2.20	67%	1.07	1.78	66%	2.05	91%	1.39	1.88	35%	1.92	38%